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GB 401675  
GB 370994  
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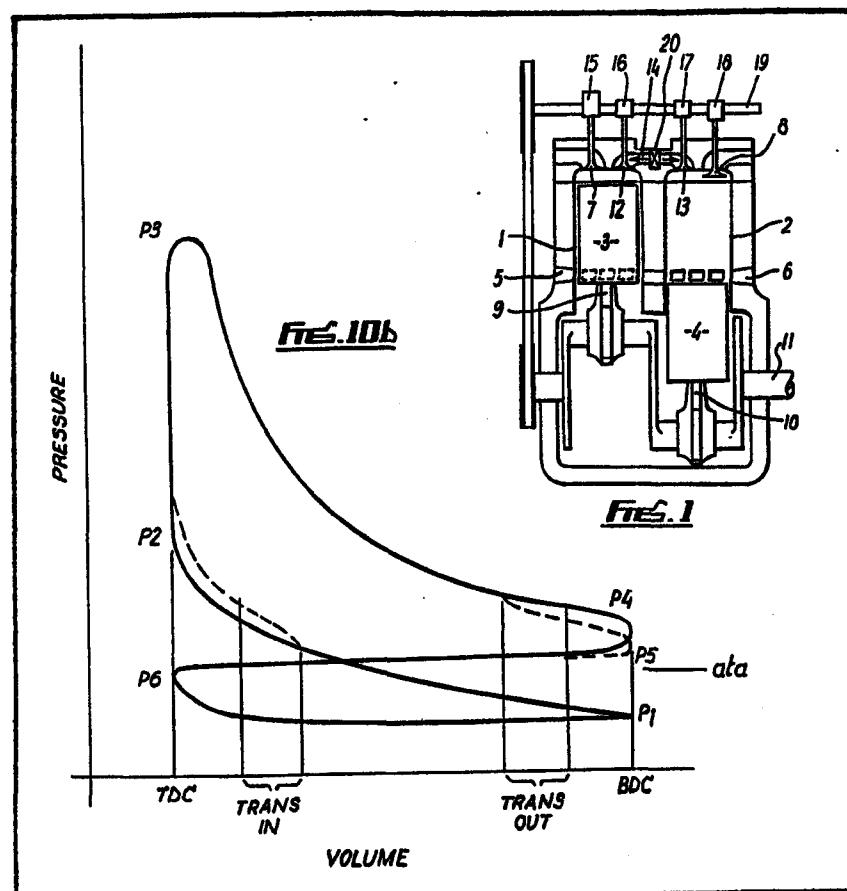
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## (54) Exhaust Gas Recirculation in an Internal Combustion Engine

(57) A multicylinder internal combustion engine comprises a transfer duct 14 connecting two cylinders 1 and 2 and transfer valves 12 and 13 operative to open and close the duct to allow some exhaust gas to transfer from one cylinder to the other to preheat the charge in that cylinder

near the end (P<sub>1</sub>) of that cylinder compression stroke (P<sub>1</sub> to P<sub>2</sub> Fig. 10b). Transfer takes place before the exhaust valve 7, 8 in the said one cylinder has opened (P<sub>4</sub>) and if desired opening of the exhaust valve may be delayed. The duct may be defined within or external to the cylinder block and is as short as possible and the transfer valves may be cam operated from a camshaft 19 driven from the camshaft 11.



The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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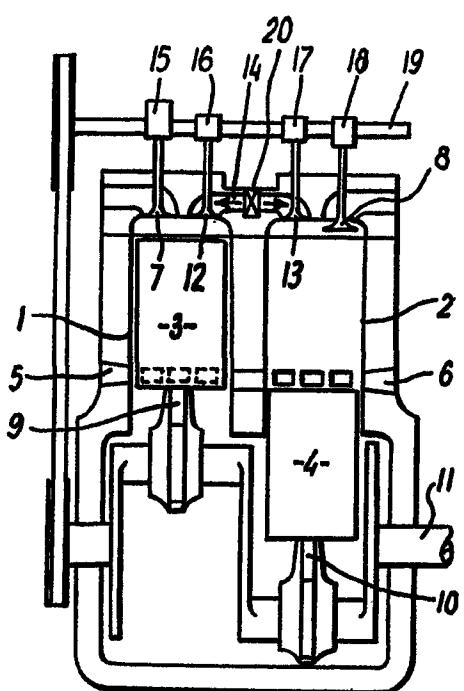


FIG. 1

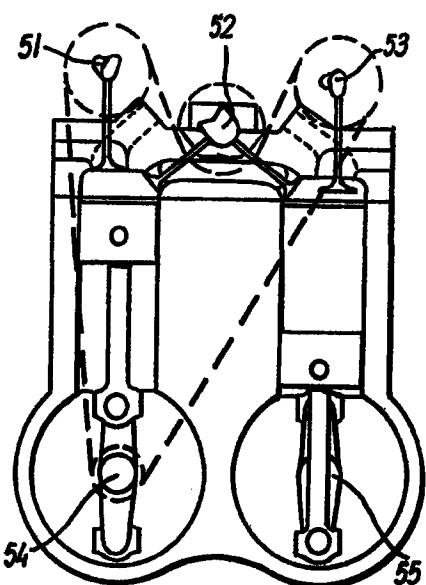


FIG. 2

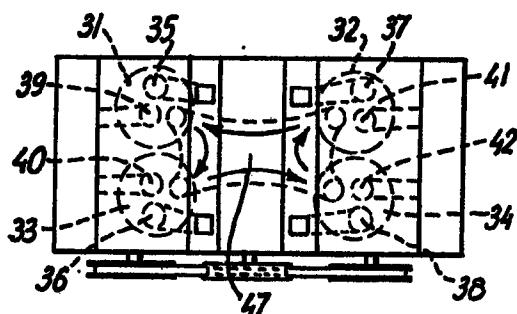


Fig. 3

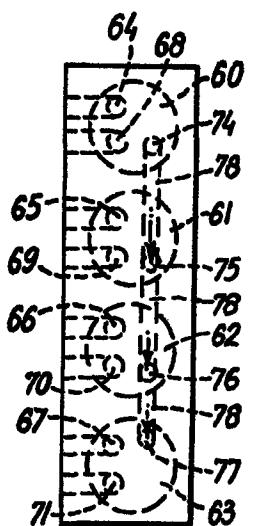
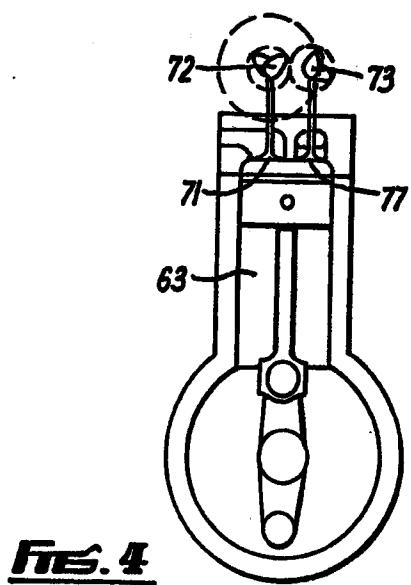


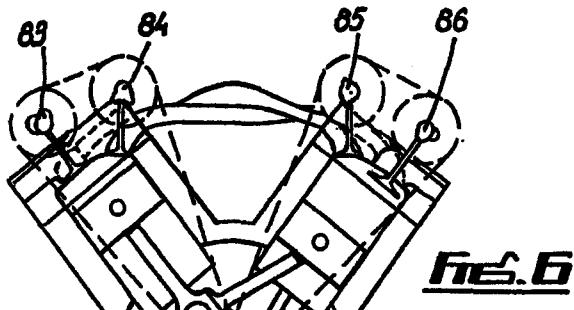
FIG. 5



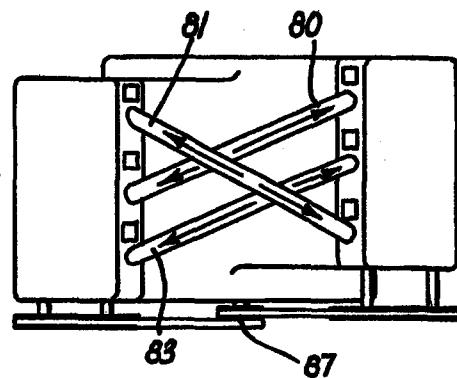
**FIG. 4**

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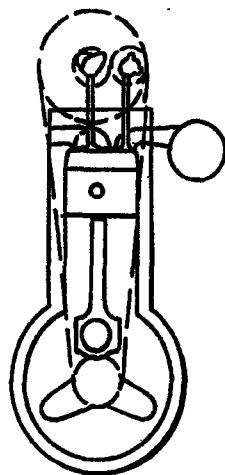
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## Fig. 6



**Fig. 7**



## Fig. 8

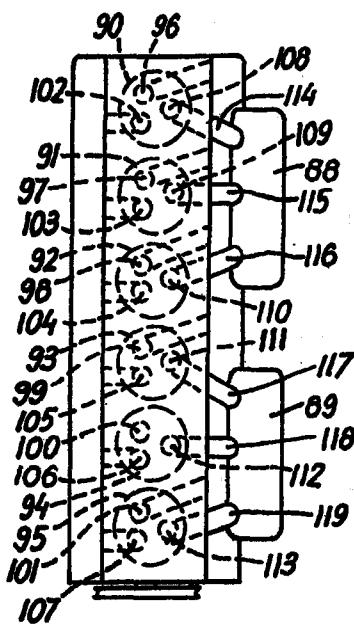
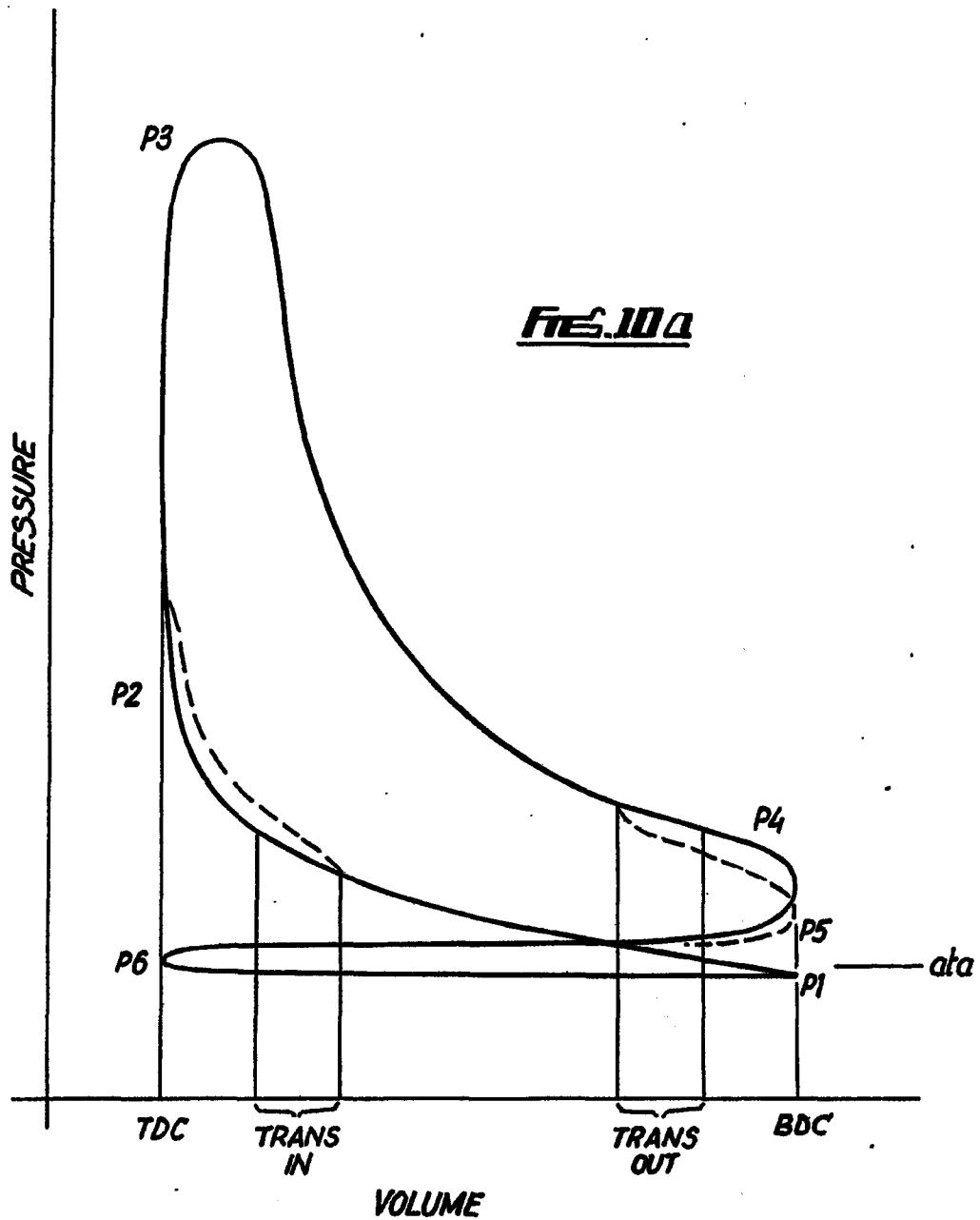


Fig. 9

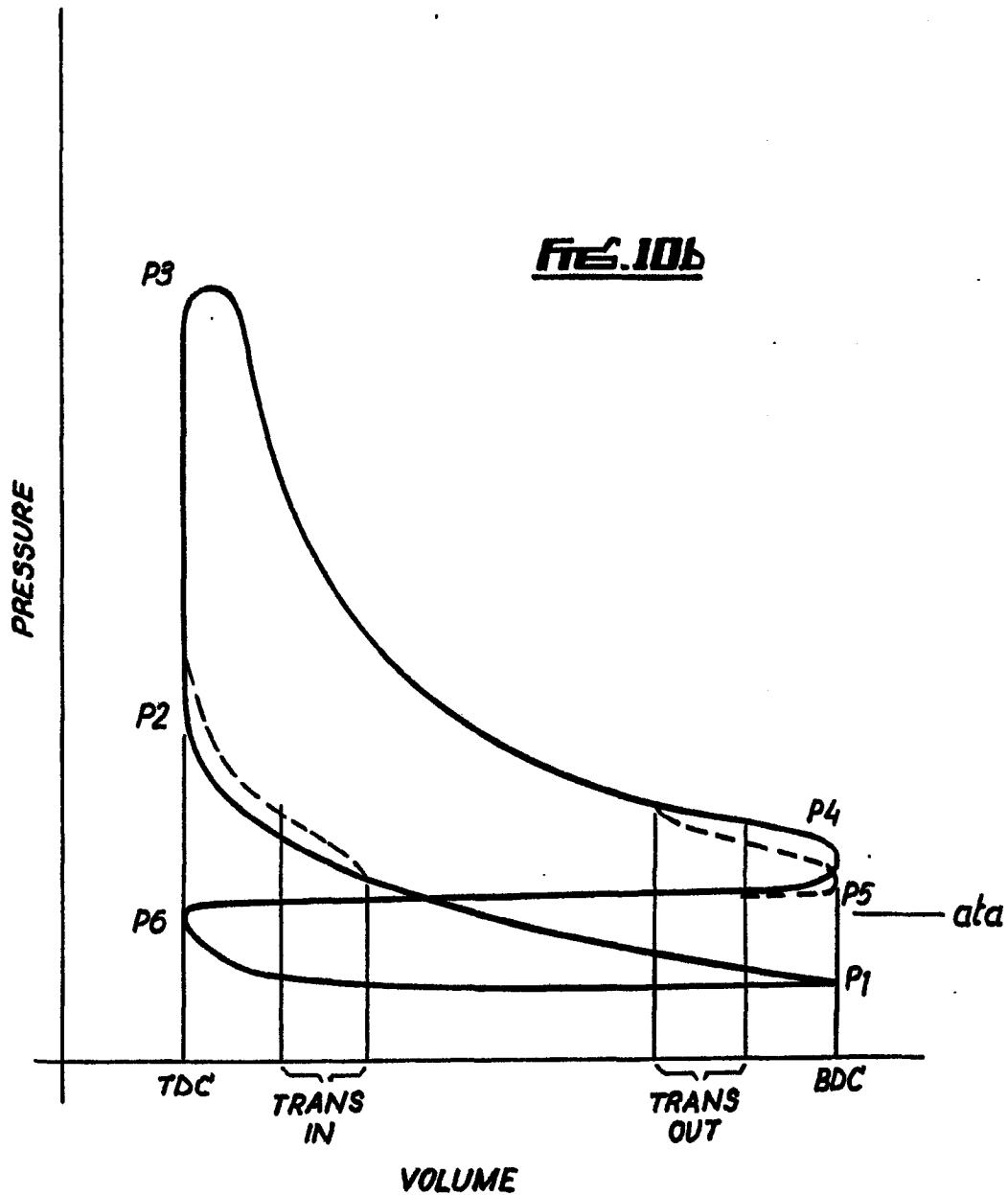
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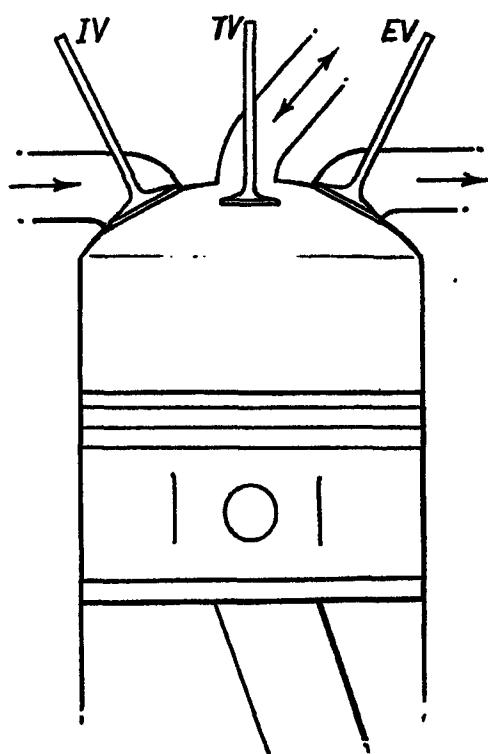


FIG. 11a

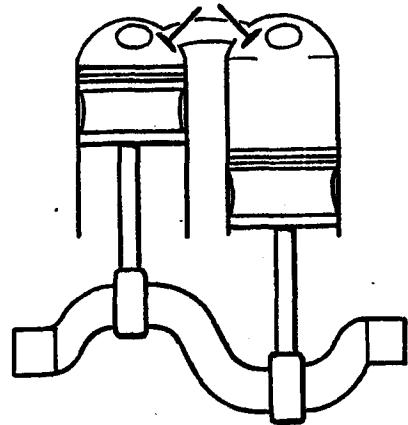


FIG. 11b

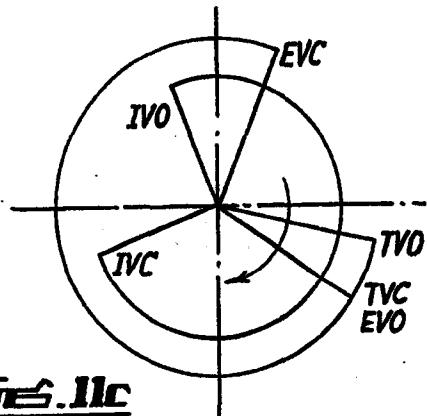


FIG. 11c

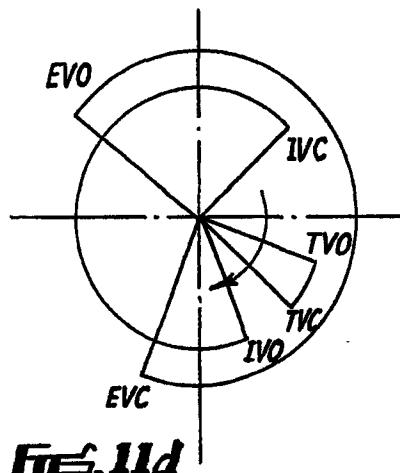


FIG. 11d

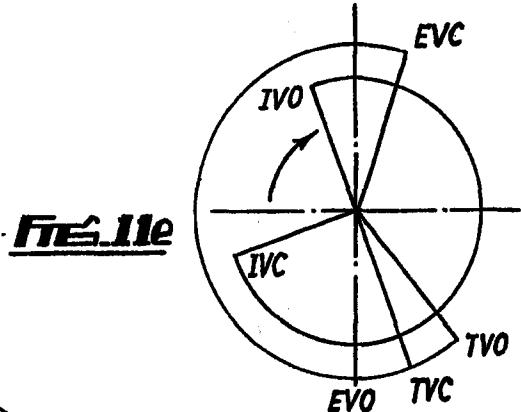


FIG. 11e

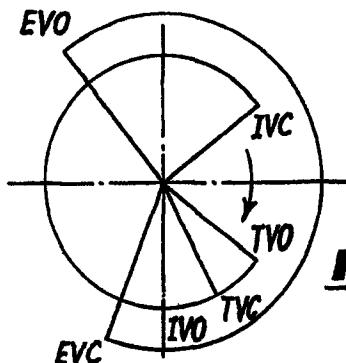
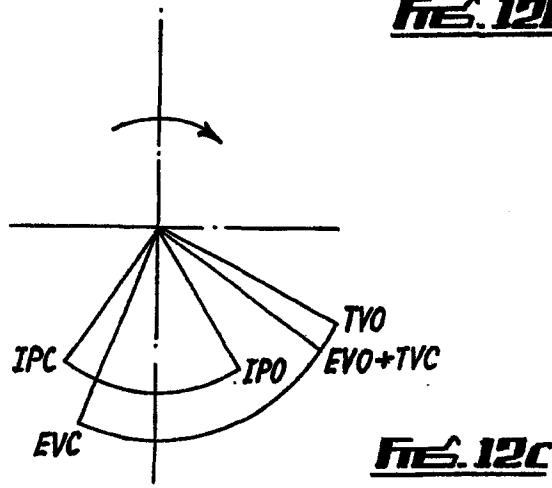
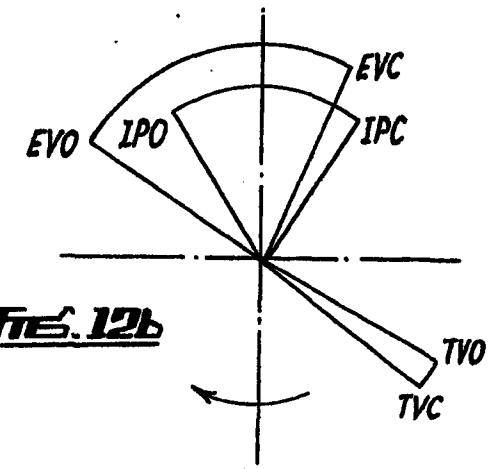
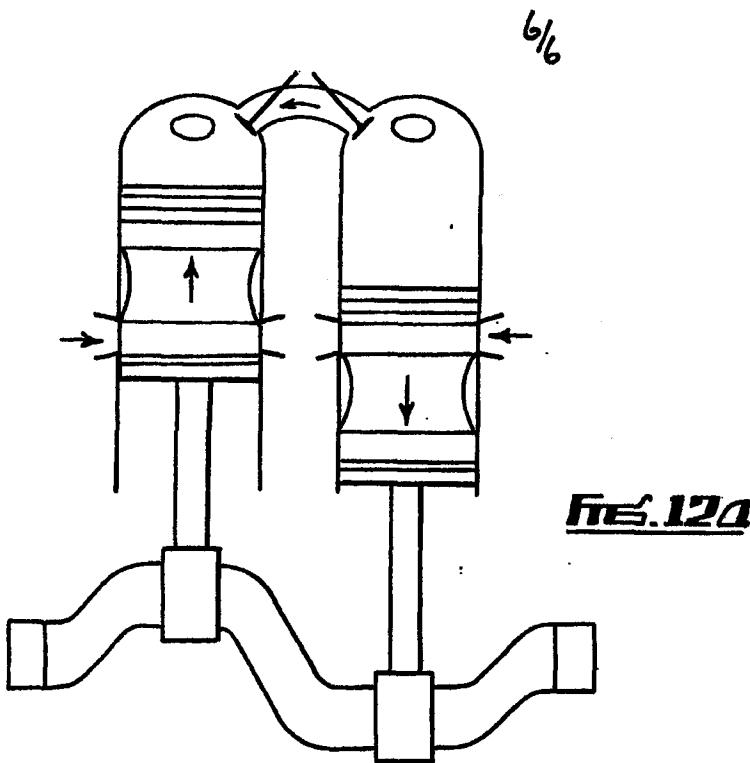


FIG. 11f

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**SPECIFICATION**  
**An Internal Combustion Engine**

The present conventional internal combustion engine whether designed to operate on the compression ignition diesel or premixed charge or stratified charge principle is inefficient in that a considerable proportion of the heat content of the fuel is unused and is carried away in the exhaust gases. Certain devices such as exhaust turbines and turbochargers have been developed in an effort to recuperate some of this waste. However, these devices are not ideal in that they involve separate machinery, their installation is often cumbersome and their characteristics in the absence of yet further special control systems seldom readily suit the internal combustion engine.

Additionally there is presently a need on many engines to provide a means of recirculating a proportion of the exhaust products to be included with the fresh cylinder charge as a means of reducing the generation of oxides of nitrogen in the cylinder which occurs during the high temperature phase of combustion. Present devices achieve this by introducing a proportion of exhaust products into the induction system to be inhaled with the fresh charge with the result that the weight of fresh charge is reduced with a corresponding reduction in engine power.

The present invention seeks to offer an improvement in the thermal efficiency of the internal combustion engine itself by re-employing a certain proportion of the waste heat in the exhaust to preheat the charge in the cylinder at the end of compression so that a proportionate reduction in the amount of fuel required to be added can be made for the same work output: in other words the specific fuel consumption is reduced. Further by introducing the exhaust gas at or near the end of the compression stroke rather than during the induction stroke there is no displacement of fresh charge.

According to one aspect of the present invention, there is provided an internal combustion engine comprising a cylinder a piston disposed in the cylinder an inlet leading into the cylinder, an exhaust leading from the cylinder, a transfer valve leading into the cylinder and control means operative to open the transfer valve near the end of the compression stroke to allow a preheated gas charge to be forced into the cylinder.

An advantageous embodiment of the invention may comprise any one or more of the following preferred features:

(a) The internal combustion engine is a multicylinder engine and a transfer valve allows the exhaust products from one cylinder to be fed to another.

(b) The internal combustion engine is a two-cylinder two-stroke engine.

(c) The internal combustion engine is a four-cylinder four-stroke engine.

65 cylinder four-stroke engine.  
 (e) The internal combustion engine is an eight-cylinder four-stroke engine.  
 (f) The piston of the cylinder of the engine of (a) from which exhaust gas products are taken is 180° out of phase with the piston of the cylinder to which the exhaust gas products are transferred.  
 (g) In the internal combustion engine of (a) the transfer valve is disposed at one end of a transfer duct joining the two cylinders.  
 70 (h) The duct length of the duct of (g) is as short as possible.  
 (i) The flame trap is disposed in the transfer duct of (g) or (h).  
 (j) The control means comprises a cam  
 80 operative to open the transfer valve shortly before the opening of the exhaust.  
 (k) The cam of (j) is supported on a camshaft and means are provided for driving the camshaft at the same speed as the crankshaft of the engine.  
 85 According to another aspect of the present invention, there is provided a multicylinder internal combustion engine in which each cylinder comprises an exhaust, an inlet and a transfer valve, the transfer valve being disposed in a transfer duct connecting the cylinder to the other cylinder and in which control means are provided operative to open the transfer valve to allow exhaust gases from one cylinder connected to the duct to be transferred to the other cylinder connected to the duct near the end of the compression stroke of the other cylinder.

The invention also comprises a method of operating a multicylinder engine in which part of the combustion products of one cylinder are transferred to another cylinder shortly before top dead centre of the piston in that other cylinder. To this end the transfer valves in the transfer duct connecting the two cylinders are advantageously simultaneously opened shortly before the opening of the normal exhaust valve or port. This latter opening may be delayed if necessary. In this way, exhaust gases from the first cylinder are driven by the residual overpressure in that cylinder into the second cylinder near the end of its compression stroke.

In order that the invention may be more clearly understood, several embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in

110 which:

Figure 1 shows a two cylinder two stroke internal combustion engine,

Figure 2 shows an end elevational view of a four cylinder four stroke internal combustion engine,

Figure 3 shows a plan view of the engine shown in Figure 2,

Figure 4 shows an end elevational view of another form of four cylinder four stroke internal combustion engine,

Figure 5 shows a plan view of the engine shown in Figure 4,

Figure 6 shows an end elevational view of a V-

Figure 7 is a diagrammatic plan view of the engine shown in Figure 6.

Figure 8 shows an end elevational view of an in line six cylinder four-stroke engine.

5 Figure 9 is a diagrammatic plan view of the engine shown in Figure 8.

Figures 10a and 10b are graphs of the pressure/volume relationship for a four-stroke engine at full and part throttle respectively.

10 Figures 11a to 11e respectively show practical valve event timing for a four-stroke engine, and Figures 12a to 12c respectively show practical valve event timings for a two-stroke engine.

Figure 1 illustrates a uniflow two-stroke engine in which a proportion of the exhaust charge can be transferred directly between cylinders which are 180° out of phase. The two cylinders are referenced 1 and 2 respectively corresponding pistons 3 and 4, inlets 5 and 6, and exhaust valves 7 and 8. The pistons 3 and 4 are mounted via con rods 9 and 10 on a crankshaft 11 in the usual way. Two further transfer valves 12 and 13 are disposed in respective cylinders 1 and 2 and at opposite ends respectively of a transfer duct 14. The exhaust and transfer valves are operated by cams 15 to 18 supported on a cam shaft 19 toothed belt driven from the crankshaft 11. The gas transfer passage 14 between the cylinders is direct and of low volume, and the charge can readily retain its heat. The camshaft 19 runs at crankshaft speed and employs a conventional cam profile. A flame trap 20 is disposed in the transfer ducts to prevent the occurrence of uncontrolled ignition.

25 Figures 2 and 3 illustrate a four cylinder four-stroke internal combustion engine with the cylinders 31 to 34 in square form. Each cylinder includes an inlet valve 35 to 38, an exhaust valve 39 to 42 and a transfer valve 43 to 46. A common plenum chamber 47 connects the transfer valves together as shown in Figure 3 and arrows indicate the flow of exhaust gases during operation of the engine. The valves are opened and closed by cams supported on three overhead camshafts 51 to 53 toothed belt driven from one of two crankshafts 54 and 55. The square four layout allows direct transfer of the charge. The path for the gases is short, and could be reduced further by inclination of the cylinder axes if required.

30 Figures 4 and 5 respectively illustrate side elevational and plan views of a four cylinder in line four-stroke engine. The cylinders are respectively referenced 60 to 63, inlet valves 64 to 67, exhaust valves 68 to 71, cam-shafts 72 and 73 and transfer valves 74 to 77. The transfer valves are connected as shown by transfer ducts 78 which are all in line. Here again the exhaust gas transfer is direct although this arrangement may not be so satisfactory as the square arrangement of the engine of Figures 2 and 3 as the disproportion in the path lengths between the outer cylinders 60 and 63 and the inner and adjacent cylinders 61 and 62 could cause

65 problems of uneven distribution of the transferred charge.

Direct transfer can also be employed in a V six four-stroke engine. A side elevational and plan view of such an engine are shown in Figures 6 and 7 respectively. The timing of the transfer phase will dictate the angle of the V. Free choice of V angle is available if a reservoir is employed, but some loss of efficiency is to be expected from the increased volume and surface area. In Figure 7 the transfer ducts are referenced 80 to 82 and the direction of exhaust gas flows by arrows. Overhead cams or camshafts 83 to 86 driven from the camshaft 87 open and close the various inlet exhaust and transfer valves.

80 In the above described four-stroke engines of Figures 2 to 7, the cam operating the transfer valves illustrated has two lobes spaced 90° apart. The camshaft runs at half crankshaft speed. The relation between camshaft and crankshaft speeds is dependent on the lobe spacing of the cams and any satisfactory permutation of these three factors may be used.

85 Other four-stroke engine layouts, viz: in line six cylinder, flat six, V eight, require a gas reservoir to be employed. Employment of such a reservoir gives freedom to vary the timing of the transfer phase unaffected by and without restricting the cylinder configuration. In the in line six cylinder engine illustrated in Figures 8 and 9 two separate chambers 88 and 89 are used to keep transfer volumes low and path lengths to a minimum. The six cylinders are referenced 90 to 95, inlet valves 96 to 101, exhaust valves 102 to 107 and transfer valves 108 to 113. The three transfer valves 108 to 110 lead via respective transfer ducts 114 to 116 to chamber 88 and the three transfer valves 111 to 113 via respective transfer ducts 117 to 119 to the chamber 89. Such chambers are preferably insulated to minimise heat loss, and passages in general are uncooled.

90 Figures 10a and 10b illustrate the pressure/volume diagrams typical of a four-stroke engine unthrottled, and at part throttle where a throttle is employed, and indicate the areas of gas transfer. The induction part of the cycle is represented between P6 and P1, compression between P1 and P2, combustion between P2 and P3, expansion between P3 and P4, exhaust blowdown between P4 and P5, and exhaust pumping between P5 and P6. The transfer periods to and from the cylinder are shown, together with the modifications to the pressure/volume diagram that result (shown dotted).

95 Figures 11a diagrammatically shows the three valve arrangement of one cylinder, Figure 11b the out of phase arrangement of two adjacent cylinders and Figures 11c to 11f the points at which the various valves open for different engine conditions in the course of an engine cycle. In both Figure 11 and 12 the letter references indicate the following:

IV Inlet valve

FV Exhaust valve

TV Transfer valve  
IVO Inlet valve open  
IVC Inlet valve closed  
IPO Inlet port open  
5 IPC Inlet port closed  
EVO Exhaust valve open  
EVC Exhaust valve closed  
TVO Transfer valve open  
TVC Transfer valve closed

10 Thus in the above described engines, a proportion of the heat energy containing exhaust gases from the first cylinder are driven by the residual overpressure in that cylinder into the second cylinder near the end of its compression

15 stroke and shortly before the injection of fuel, or the occurrence of the spark in a premixed charge engine, to provide both preheating of the charge to the benefit of thermal efficiency and exhaust gas re-circulation to the benefit of exhaust

20 emissions. Additionally by the location, direction and shaping of the above extra valve port or gas transfer means it is possible to influence the movement and distribution of the trapped charge at and around piston top dead centre position to

25 influence combustion and charge stratification if required. In Figures 11b and 12a the first cylinder is the left-hand cylinder and the second cylinder is the right-hand cylinder. Figures 11d, 11f and 12b relate to the first cylinder and Figures 11e, 11c

30 and 12c relate to the second cylinder.

In a practical design of such a system the transfer port means should be sufficiently direct as to avoid undue losses due to duct length or volume, and this has to be considered in the

35 cylinder layout of the engine.

Also in the case of the premixed charge engine the amount of charge preheating cannot be unlimited or detonation of the charge will occur.

Figure 12a represents the 180° out of phase

40 arrangement of two adjacent cylinders of a two-stroke engine and figures 12b and 12c the position at which the various valves open and close in the course of a cycle.

It will be appreciated that the above

45 embodiments have been described by way of example only and that many variations are possible without departing from the scope of the invention. In particular, any suitable cylinder arrangement may be used. For example, in

50 addition to those described a parallel twin, eight cylinder in-line, V8 or flat 4 may equally well be used.

Although in the above described examples, the valves are opened by overhead cams supported

55 by toothed-belt driven overhead camshafts any suitable valve disposition and method of valve opening may be used.

The transfer passage between cylinders may be internal or external to the engine block. If

60 internal, it should advantageously be uncooled. An external passage may be formed of a suitable material and disposed across the top of the engine block. Having an internal passage obviates any sealing problems as the passage is defined by

65 the material of the block itself.

Under some circumstances, it may be advantageous to control the opening of the transfer valves in dependence upon an operating characteristic of the engine such as engine speed or load. Such control may be mechanical or electronic as desired.

Also under some circumstances it may be advantageous to employ a throttle valve in the transfer passage to limit the mass of gas transfer in dependence upon an operating characteristic of the engine such as engine speed or load. Control of such throttle valve may be mechanical or electronic as desired. The throttle valve may be placed in a position similar to that of the flame trap 20 shown in Figure 1.

#### Claims

1. An internal combustion engine comprising a cylinder, a piston disposed in the cylinder, an inlet leading into the cylinder, an exhaust leading from the cylinder, a transfer valve leading into the cylinder and control means operative to open the transfer valve near the end of the compression stroke to allow a preheated gas charge to be forced into the cylinder.
2. An internal combustion engine as claimed in Claim 1, which is a multicylinder engine and in which the transfer valve allows the exhaust products from one cylinder to be fed to another.
3. An internal combustion engine as claimed in Claim 1 or 2, which is a two-cylinder two-stroke engine.
4. An internal combustion engine as claimed in Claim 1 or 2, which is a four-cylinder four-stroke engine.
5. An internal combustion engine as claimed in Claim 1 or 2, which is a six-cylinder four-stroke engine.
6. An internal combustion engine as claimed in Claim 1 or 2, which is an eight-cylinder four-stroke engine.
7. An internal combustion engine as claimed in Claim 2, in which the piston of the cylinder of the engine from which exhaust gas products are taken is 180° out of phase with the piston of the cylinder to which the exhaust gas products are transferred.
8. An internal combustion engine as claimed in Claim 2 or 7, in which the transfer valve is disposed at one end of a transfer duct joining the two cylinders.
9. An internal combustion engine as claimed in Claim 8, in which the duct length of the transfer duct is as short as possible.
10. An internal combustion engine as claimed in Claim 8 or 9, in which a flame trap is disposed in the transfer duct.
11. An internal combustion engine as claimed in Claim 2, or in any of Claims 3 to 10 when appendant to Claim 2, in which the control means comprises a cam operative to open the transfer valve shortly before the opening of the exhaust of the said one cylinder.
12. An internal combustion engine as claimed in Claim 11, in which the cam is supported on a

camshaft and means are provided for driving the camshaft at the same speed as the crankshaft of the engine.

13. A multicylinder internal combustion engine in which each cylinder comprises an exhaust, an inlet and a transfer valve, the transfer valve being disposed in a transfer duct connecting the cylinder to the or another cylinder and in which control means are provided operative to open the 5 or each transfer valve to allow exhaust gases from one cylinder connected to the duct to be transferred to the other cylinder connected to the duct near the end of the compression stroke of the other cylinder.

10 14. A method of operating a multicylinder internal combustion engine in which part of the combustion products of one cylinder are transferred to another cylinder shortly before top dead centre of the piston in that other cylinder.

15 15. A method as claimed in Claim 1, in which the products of one cylinder are transferred to another cylinder through a transfer duct.

20 16. A method as claimed in Claim 15, in which the transfer through the transfer duct is governed by transfer valves which are opened simultaneously.

25 17. A method as claimed in Claim 16, in which the exhaust valve of the said one cylinder is opened after the opening of the transfer valves so that the residual overpressure in that cylinder drives the exhaust gas over into the other cylinder.

30 18. A method as claimed in Claim 17, in which the exhaust valve opening in the said one cylinder is delayed.

35 19. An internal combustion engine substantially as hereinbefore described with reference to Figures 1 and 12, or Figures 2, 3, 10 and 11 or Figures 4 and 5, or Figures 6 and 7, or Figures 8 and 9 of the accompanying drawings.

40 20. A method of operating a multicylinder engine substantially as hereinbefore described with reference to Figures 1 and 12, or Figures 2, 3, 10 and 11 or Figures 4 and 5, or Figures 6 and 7, or Figures 8 and 9 of the accompanying drawings.

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